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Realization of a Four Port Directional Coupler Using Two Dimensional Photonic Crystal Structure

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ABSTRACT

In this paper we have proposed a two dimensional Photonic crystal structure (PCS) for realizing a directional coupler using line defect by introducing titanium dioxide rods. A Gaussian modulated continuous wave of 1900 nm is used as input and its corresponding output is obtained at the opposite facet of the structure. Simulations are done based on finite difference time domain (FDTD) method.

Keywords: Photonic crystal structure, Directional coupler, FDTD method.

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1. INTRODUCTION

Photonic crystals are today used as a general term describing periodic structures both in one dimension, two dimension and three dimension. Photonic technology promises much faster computing, massive parallel processing, and an evolutionary step in the digital age. Photonics acts as an attractive alternative to electronics technology due to the advantages of information processing in optical domain. In recent years, Photonic crystal based optical devices have attracted significant research, due to its ability to interact with light on a wavelength scale. Light is transmitted very fast through this structure and supports the concept of photonic bandgaps. Here, the periodicity of the refractive index (i.e. dielectric constant) gives rise to photonic bandgaps (PBG), forbidden energy bands for photons[1].

PCS finds its application in various optical devices such as optical switches, nonlinear lenses, polarization rotators,

compact pulse compressors, frequency converters, optical diodes etc[2-5].

Directional coupler are used in microwave application. In this area very few papers are found in literature. M. Tokushima *et al*.[6], have already proposed a three port directional coupler using line defect waveguide. T. F. Krauss *et al*.[7] have designed a vertical directional coupler based on photonic crystal structure for filtering action. Here, a supercontinuum source (Koheras Super-K Compact) was used to characterize the device in the wavelength range from 1300 nm to 1650 nm.

In this paper, a PCS has been proposed to realize a four port directional coupler so that it can be used in photo integrated circuits (PIC) for microwave application. Here, a Gaussian modulated continuous wave of 1900 nm is used as input and its corresponding output is obtained at the opposite facet of the structure..

2. THEORY

For analyzing photonic crystal structure, various types of computational methods have been adopted. They are: plane wave expansion (PWE) method, transfer matrix method, Green's function method and finite difference time domain method. Finite difference time domain (FDTD) method is mostly used for computation of band gap of a PCS[8]. According to Qiu, FDTD method can be successfully applied to the photonic crystal in the computation of band structure for calculation of defect modes, waveguide modes and surface crystals. According to Yee's algorithm[9], PCS can be implemented in two dimensional hexagonal structures. A region of space is selected for field sampling in space and time. At t=0, all the fields in the sampling region are zero. Mode radiation is investigated by implementation of central difference approximation of Maxwell's equations. A perfectly matched layer (PML) has been applied to ensure uniqueness and validity of the numerical solution of Maxwell's equations inside the computation domain. The time dependent Maxwell's equation are discretized using central-difference approximations to space and time partial derivatives.

The central difference approximation is as follows

$$f'(\chi_0) = \frac{f(\chi_0 + \Delta x) - f(\chi_0 - \Delta x)}{2\Delta x} \quad (1)$$

In this study, the temporal step is 2x10^{-17} s, the spatial step is λ/40, where λ is the wavelength of the signal. The condition of stability is also achieved as it fulfills:

$$\Delta t < \frac{1}{c}\left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2}\right)^{-\frac{1}{2}} \quad (2)$$

Where, Δx and Δy are the increments in X and Y direction.

The basic function of PCS is that it controls the recombination of an electron-hole pair in a semiconductor during spontaneous emission. Such that when optical transition is occurred within this structure, bandgap overlapping exists. The propagation over this crystal can be closely equivalent to the electronic properties of semiconductor[10].

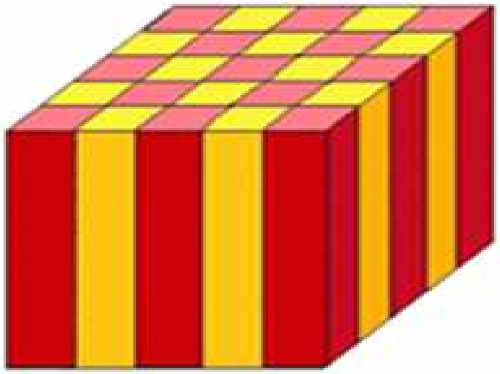

Fig.1. Two dimensional photonic crystal structure

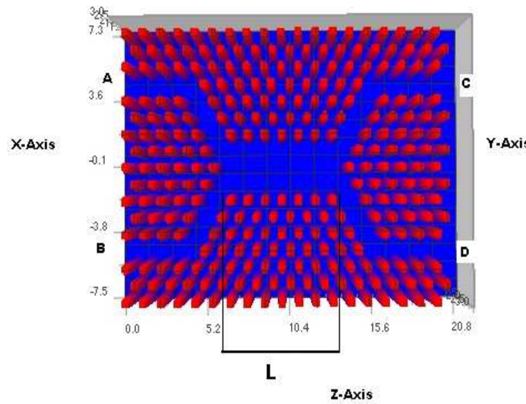

Fig.2 Structure of the directional coupler

But most of the applications like integrated optics are intended solely in the plane of periodicity. To overcome this problem, the best methodology is accepted. This is one of the new advance technology named as Nanotechnology[11]. Here, the structural arrangement consists of titanium dioxide rods placed on the air wafer giving rise to the difference in refractive index so that light can propagate easily. The basic function of a directional coupler is to operate on an input so that two output signals are available. However, when the input is applied to the opposite port of an internally terminated coupler, only one output signal is produced.

3. RESULT AND DISCUSSIONS

In this paper, we have considered the wafer to be of air having dimension of 21 µm length and 15 µm width. Then the titanium dioxide rods are periodically arranged having radius 0.3 µm with a refractive index of 3. In order to realize the structure a line defect is created as shown in figure 2.

In the above figure 2, port A and B are input ports, L is the coupling region where the signals are coupled and port C and D are the output ports. Here, Gaussian modulated continuous signals of 100V/m amplitude are given as input at A and B ports with a half width of 0.8 µm. So that the output signal can be obtained at the ports C and D.

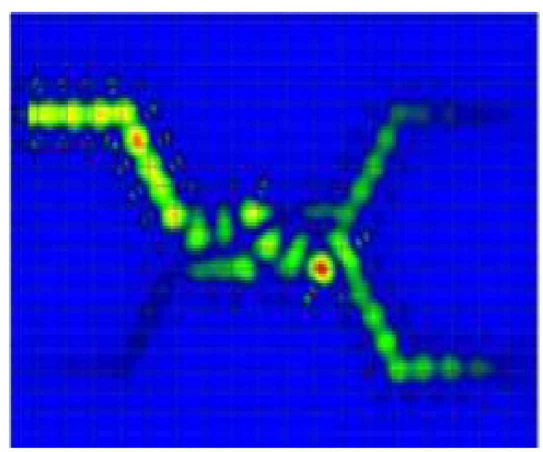

Fig. 3a. Field distribution when the input is at port A

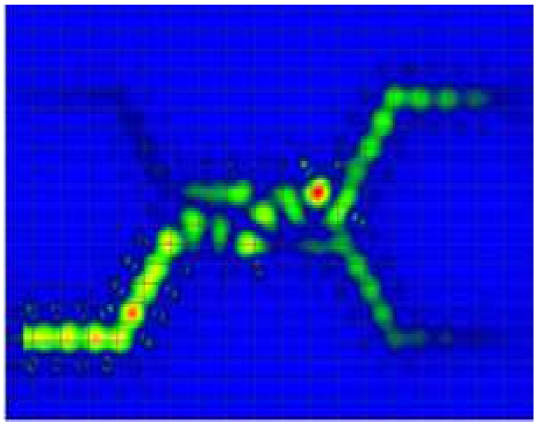

Fig. 3b. Field distribution when the input is at port B

When the input signal is given in both the ports A and B simultaneously, we find the resultant distribution to be zero as shown in Figure 3c.

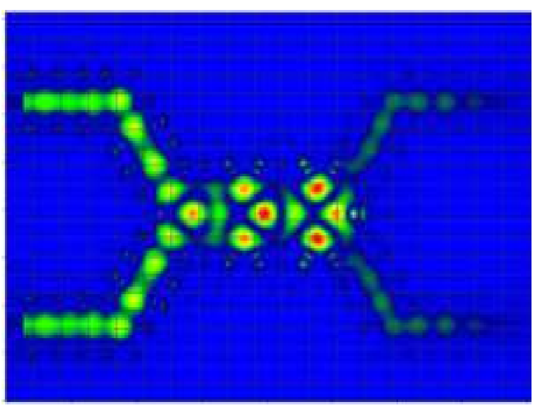

Fig. 3c. Field distribution when the input is at both the ports A and B

The field distributions for different states of the input signal are as shown in the figure 2. The input signal is given at 4.05µm which is named as Port A along X-axis and the field distribution of the corresponding output is at end facet along Y-axis as shown in Figure 3a. Similarly by feeding signal at -4.55 µm as Port B, the corresponding output can be realized as shown in Figure 3b.

CONCLUSION

From the above discussions we may conclude that two dimensional Photonic crystal structure with line defect can be realized as a directional coupler. The structure can be also modified suitably, to realize other functions like logic operations, switches. Some interesting results are found based on this[12,13]. However for actual realization of these elements, efficiency of the output should be enhanced.

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